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Costello
**Solar Demonstrating
Globe**

By
Garrett P. Serviss



Manufactured by

Weber Costello Company

CHICAGO HEIGHTS,



ILLINOIS

22.2

Globes Hyloplate Blackboards Erasers—Wall Maps

And Other

SCHOOL SUPPLY
SPECIALTIES



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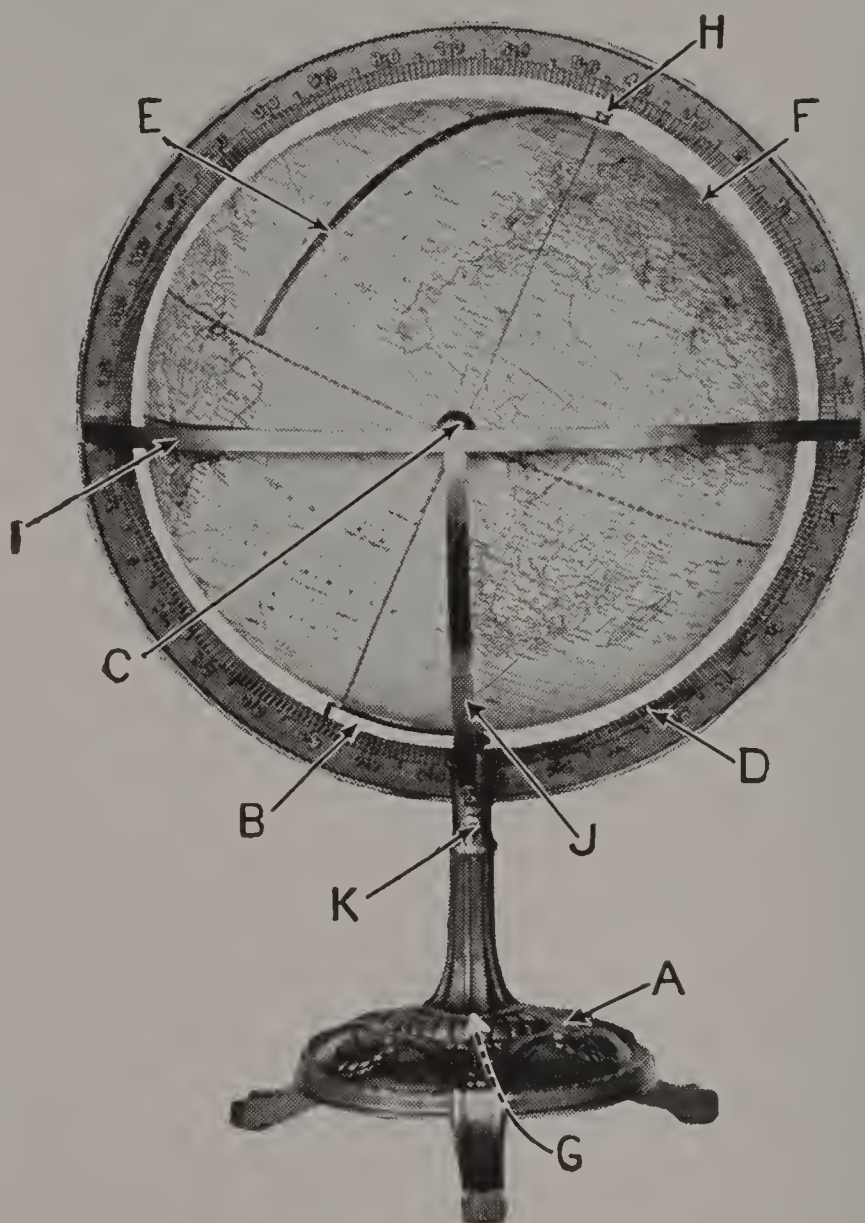
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The following subjects are included in this Manual because of their relation to the preceeding matter and their educational value. The Costello Solar Demonstrating Globe is not, however, suited to use in conjunction therewith:

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COSTELLO SOLAR DEMONSTRATING GLOBE

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Patent Applied For*



LIST OF PARTS

A—Globe Base.
B—Inclination Plate.
C—Sun.
D—Day and Night Circle.
E—Quadrant.
F—Globe Ball.

G—Thumb Nut (under base).
H—Nut for Quadrant.
I—Semi Horizon.
J—Semi Horizon Support.
K—Set Screw for Day and Night Circle.

To my mind this is as admirable a means of teaching astronomy as could be imagined. The globe ought to go into every school, carrying mental daylight with it It is not only an aid to instruction—it is itself the **chief instructor**.

Garrett J. Serin

INTRODUCTION

Description of the Apparatus

The Costello Solar Demonstrating Globe is an apparatus designed to show, by visual demonstration, the effects of the relations between the sun and the earth upon the distribution of light and heat, of day and night, and of the changing conditions of the seasons. What the almanac tells, without explaining the mathematical calculations on which its predictions are based, this apparatus **shows to the eye** without the necessity of any calculations. Occasionally a little of the very simplest arithmetic is all that need be used.

The apparatus consists of an ordinary globe of the earth, "F," mounted within a vertical bronze circle "D" which represents the dividing line between day and night. This circle is called the "Day and Night Circle."

The earth globe is mounted within this circle with its polar axis inclined $23\frac{1}{2}$ degrees from a perpendicular. This inclination corresponds to that of the axis of the earth with respect to the plane of the orbit in which it travels around the sun, called also the plane of the ecliptic.

The Day and Night Circle is so mounted that it can be freely swung round a vertical axis into any desired position.

Independently, the earth globe can be rotated on its axis inside the Day and Night Circle, the motion of neither interfering with that of the other, and both motions may be performed at the same time.

Projecting out from the Day and Night Circle on one side are two curved metal supports, one, "I," fixed horizontally, in the plane of the ecliptic, while the other, "J," is vertical. These sustain at their point of junction, exactly over the center of the Day and Night Circle, and at a distance from it equal to the radius of the Circle, a small bronze ball, "C," which represents the sun. A projecting point on the inner side of this sun-ball is called the "Sun's Central Ray," its purpose being to show over what point on the earth the center of the sun is vertical at any time. The sun-ball of course moves with the Day and Night Circle to which it is attached by the supports, remaining at a distance of 90 degrees from that circle on all sides.

On the "sun" side of the Day and Night Circle, and at the bottom, is a small thumb-screw, "K," by means of which the Circle, and with it the sun, can, when desired, be fixed firmly in position, while the earth globe is rotated within.

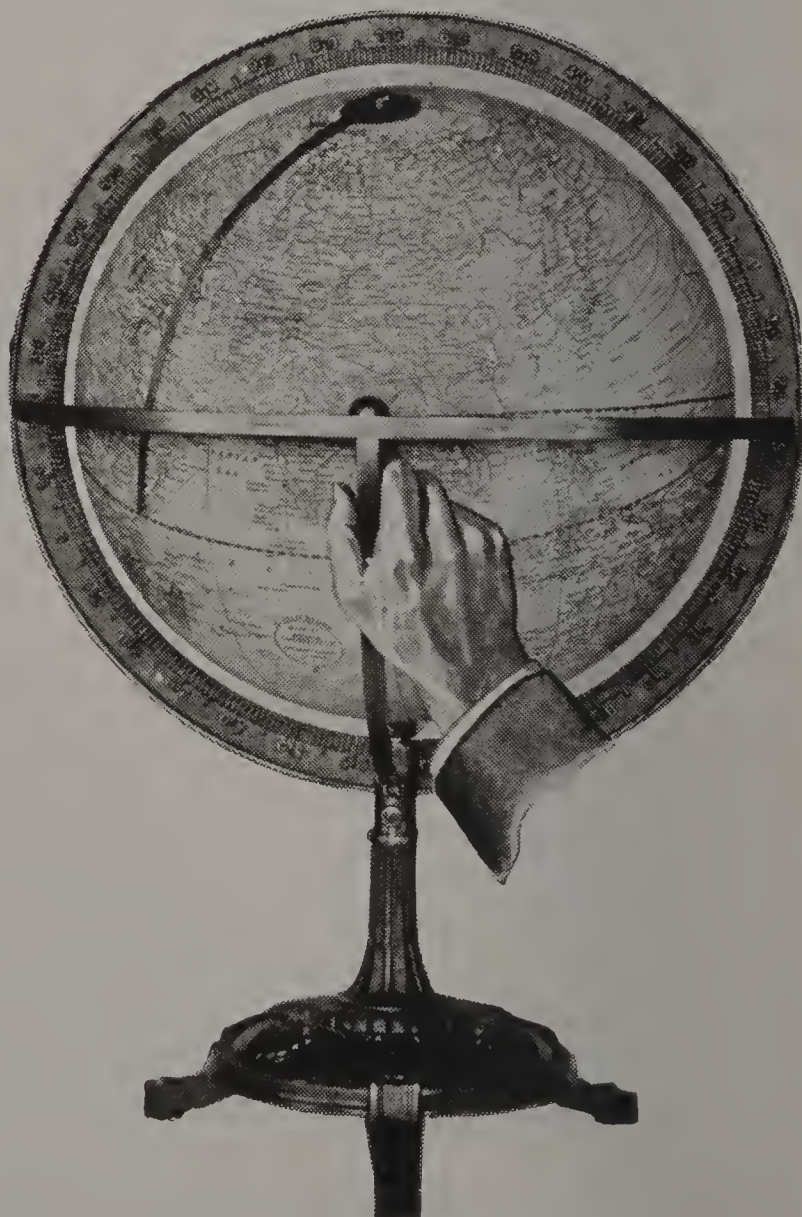
Attached by another small thumb-screw, "H," to the north pole, and curving down over the globe, is a graduated copper indicator, "E," called a "Quadrant," its length being equal to a quarter of a circle. When the screw is loosened the Quadrant may be swung in either direction over the globe, and then fixed in any position. When the Quadrant is thus fixed by tightening the screw at the north pole, and the earth is rotated, the movement of the point of the Quadrant along the equator of the globe indicates the number of degrees turned by the globe, and

this is the principal use of the Quadrant, although it may also be employed to measure the latitude of places on the globe. Its uses are indicated in the pages that follow.

When it is desired to use the Globe simply for geographical purposes, the sun-ball may be swung around to the side opposite the observer and fixed there by means of the thumb-screw at the bottom. The north pole will then be under the 90th degree of latitude near the top of the circle. The meridians, or circles of longitude, on the globe are drawn 15 degrees apart, whereby they serve as hour-circles in reckoning standard time, which begins at the Prime meridian, or meridian of Greenwich, and follows the sun around westward, so that it is noon on the 15th degree west one hour after it was noon at Greenwich; noon on the 30th degree west two hours after it was noon at Greenwich, and so on.

Half way around the globe from the Greenwich meridian, i. e. 180 degrees from Greenwich counting either west or east, is the "Date Line" which runs through the middle of the Pacific ocean, and on which each new calendar day is assumed to begin. When it is noon at Greenwich, or anywhere on its meridian, it is midnight on the Date-Line. Since by the civil calendar every day begins at midnight, evidently each successive day may be said to have its birth on the Date Line, at the moment when its immediate predecessor is 12 hours old at Greenwich. (We are here using the word "day" in its astronomical significance, as the interval of time occupied by a single rotation of the earth on its axis—24 hours). When a ship crosses the Date Line sailing **eastward** it goes back a day in its reckoning, while if it crosses sailing **westward** it goes forward a day. For instance if the ship is going **from** California **to** Japan and reaches the Date Line at 10 A. M. on a Monday, it will, as soon as it is over the Line, skip to 10 A. M. Tuesday. But if the ship is sailing **from** Japan **to** California it will go back from 10 A. M. Tuesday to 10 A. M., Monday.

Although upon the whole the Date Line follows the 180th meridian, yet, as marked on the Globe it shows a number of zig-zags. These were made to include certain islands on one side or the other of the Line, whose local dates depend upon whether they were discovered by explorers coming from the east or



from the west. But in the open ocean ship captains go by the Date Line only.

The parallels of latitude run east-and-west around the Globe parallel with the equator, and are for convenience marked at intervals of 10 degrees. The pupil may be shown how, while the angular velocity of the earth's rotation is the same from the equator to the poles, the **linear** velocity, i. e. the number of miles moved per hour, is greatest at the equator and least near the poles. Standing on the pole itself a person would simply turn round and round on a vertical axis once every 24 hours.

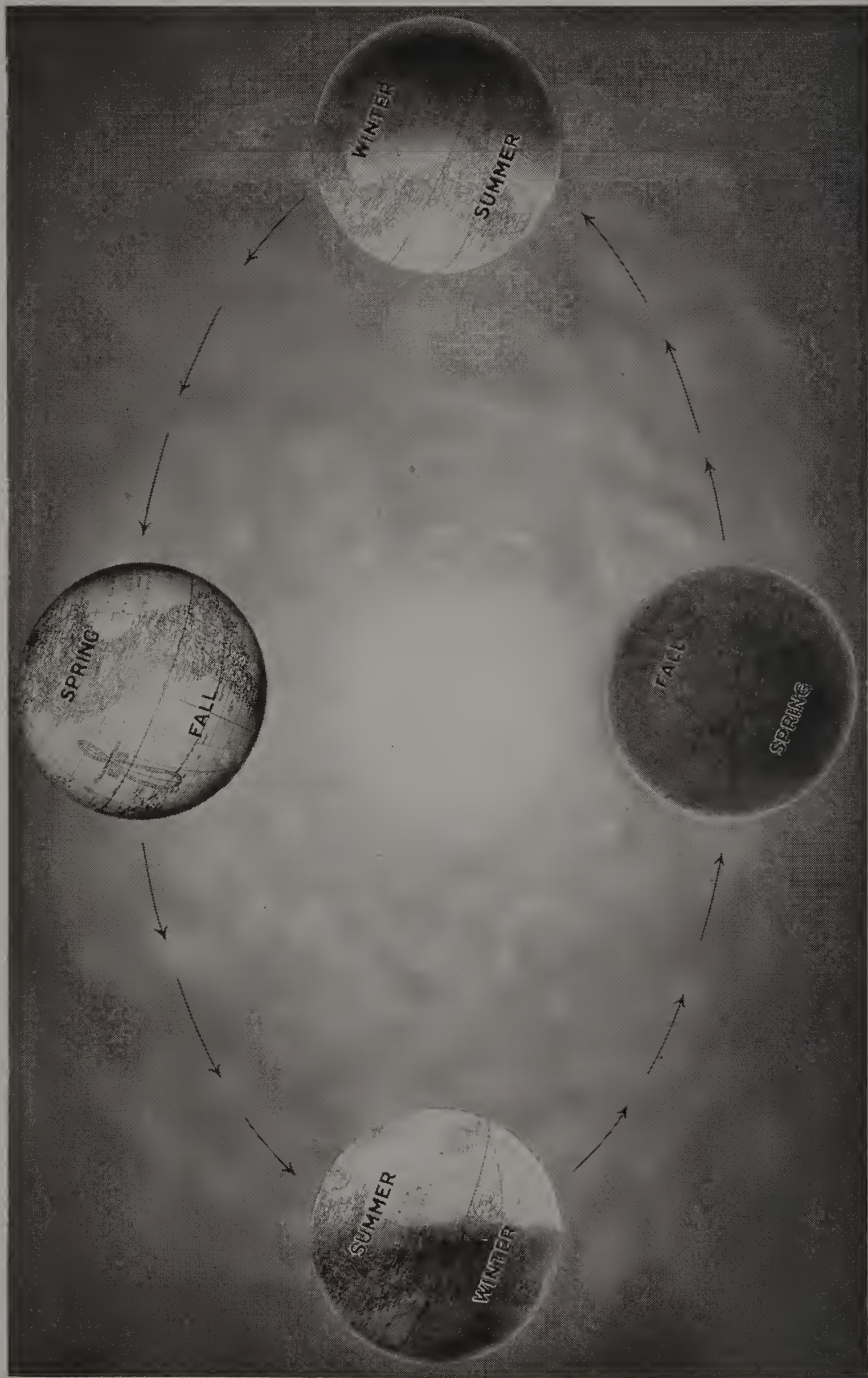
In adjusting the apparatus for use in the demonstrations described in this manual the sun-ball should be placed on the side of the Globe facing you. The simplest way to shift the position of the sun and of the Day and Night Circle is to take hold of the vertical support just under the sun-ball and move it to the right or left as desired. (See cut). To place the sun over a given date on the ecliptic circle, it is easiest to set the Globe before you with the north pole exactly under the Day and Night Circle and **inclining to the right**. The North Pole will then point to the 43rd degree N. Lat. on the Day and Night Circle. Then the ecliptic will lie horizontally, parallel with the horizontal support of the sun-ball, and, without rotating the globe, you can push the sun around to right or left until its Central Ray is exactly over any desired date. Fix it there with the thumb-screw, and then you can rotate the globe at will.

HOW TO USE THE COSTELLO SOLAR DEMONSTRATING GLOBE

It may be confidently be affirmed that a few days, or at most a week or two, of experience with this simple apparatus, will afford a better comprehension and mastery of the important and very practical field of knowledge that lies on the border between geography and astronomy, involving the relations between the earth as an inhabited planet and the sun as the source of the light and heat which make that planet habitable, than can be obtained by months of study of text-books, or of blackboard demonstrations. The pupil **sees** the phenomena virtually taking place before him, while he listens to the teacher's explanation—and in many cases the explanation stands out for itself, or a very brief examination reveals it, thus giving to the pupil that most inspiring sense of seeing and discovering with his own eyes.

And for self-instruction at home nothing could be more valuable than the Costello apparatus, while the need of something of the kind is emphasized by the fact that the majority of even educated people go through life without ever clearly understanding the simple facts on which an almanac is based. The Costello Globe makes them perfectly plain.

What follows is intended as a suggestive guide both for teachers and for those who teach themselves. We here recall the principal astronomical and geographical data concerned, and point out both how to use the apparatus, and how it may be used **in such a way as to redouble the interest of both pupil and teacher.**



Position of Earth in relation to Sun, March 21st (upper), June 22nd (left), Sept. 23rd (lower), and Dec. 22nd (right).

See pages 25 describing the procession of the equinoxes.

FUNDAMENTAL RELATIONS OF SUN AND EARTH

The continually changing phenomena of the seasons and of day and night are due to three great causes, the first two of which are **apparent motions** of the sun produced by two **real motions** of the earth, while the third cause is a permanent **inclination** of the axis of the earth, which may be likened to the peg of a top that does not stand upright while the top spins.

The two **real** motions are: (1), The rotation of the earth, once every 24 hours, on an axis running north and south through its center, from pole to pole—which is the cause of the succession of day and night; and (2), The revolution of the earth around the sun once every year in a path called its orbit,—which is one of the causes of the change of seasons; the other cause being the inclination of the axis already referred to.

The two apparent motions are: (1), The daily movement of the sun through the sky, from its rising to its setting point, or from **east to west**, which is a relativity effect due to the earth's daily rotation on its axis from **west to east**: (2), The yearly passage of the sun around the sky, against the background of the stars, which is also a relativity effect due to the earth's yearly revolution around the sun, although, in this case, the sun appears to move around in the same direction as that of the earth's motion, i. e. from **west to east**. To explain this difference let a boy stand in the middle of a circular race-track while another boy runs around the track. To the runner the motionless boy will appear to be moving around against the background in the same direction in which he is running, thus, as it were, keeping ahead of him. But if the runner stops and simply rotates on his heels, then the other boy will appear to be revolving around him in a direction opposite to his own rotation.

The **third** thing to consider is the **inclination** of the earth's axis of rotation, which, as we have said, is one of the causes of the change of seasons. Now, to what is the earth's axis inclined? To the plane in which the earth revolves around the sun, which is called both the plane of the earth's orbit and the plane of the ecliptic. Instead of spinning like a top with its peg standing straight, the rotating earth as it revolves around the sun keeps its axis always leaning one way, at an angle of $23\frac{1}{2}$ degrees from the perpendicular.

THE SUN'S DAILY MOTION—CAUSE OF DAY AND NIGHT

For convenience we shall hereafter speak of the apparent motions of the sun as if they were real, because the eye is completely deceived by them.

Let us now place the Costello Solar Demonstrating Globe before us with the sun on the side toward us, both poles under the Day and Night Circle and the north pole inclined toward the right. Observe that the earth's equator is represented by a circle of black and yellow checks running around the globe half way between the poles. There is another circle made up of black and red checks which represents the ecliptic. This runs directly under the sun and crosses the equator at two diametrically opposite points on the globe. The two circles are inclined to one another at an angle of $23\frac{1}{2}$ degrees. We shall deal with this later, but for the present we are especially concerned with the equator.

Bring the point where the equator, the ecliptic, and the north-and-south meridian, marked "Meridian of Greenwich," all cross together, to the center of the globe as it stands before you; then move the sun until its central ray is exactly over that point, and fix it there by tightening the screw "K" at the front of the Day and Night Circle. Then rotate the earth from west to east, i. e. from left to right. That is the way you would actually see it turning if you were thousands of miles up in the sky with your head to the north and your feet to the south, and looking down upon the earth.



The Cap of Day

Now, observe how as the earth turns from west to east the little bronze ball representing the sun seems to speed from east to west across the oceans and continents, keeping always over the equator. Notice that in its westward motion over the earth the sun carries a hemispherical cap of daylight with it, which fits over the half of the globe that is turned

toward the sun, reaching to the Day and Night Circle all around, but not passing beyond it. Behind that circle, on the side away from the sun, the surface of the earth is buried in night. The sun is like a center button on the top of the cap of day.

The western (left hand) rim of the Day and Night Circle shows where the sunrise line lies upon the earth, and the eastern (right-hand) rim marks the sunset line. The Circle thus marks the boundary between daylight and darkness. Every point on that circle is always 90 degrees from the sun, but the circle is constantly shifting its position westward over the surface of the globe as the earth turns on its axis. On the western verge the lands and seas are continually coming into the sunlight, or we may say that there the dawn is racing ahead of the sun, keeping 90 degrees in advance of it.

Right under the sun it is noon, but it is also noon all along a straight north-and-south line, or meridian, drawn from pole to pole through the sun's central ray, and the noon line, like the sunrise line, flies westward over the earth just as fast as the sun. Go round the earth keeping up with that line and you would always be in the noon sunshine.

Note that all places on the earth lying **west** of the noon line are in the forenoon, and all places lying **east** of that line are in the afternoon.

The Cap of Night

Then look at the eastern (right-hand) edge of the Day and Night Circle. There darkness is swallowing up daylight. It is the border of the earth's revolving night cap. The "trailing garments of the night" follow the sunshine westward over the earth. It is both interesting and very instructive to watch first Europe and Africa, then the Atlantic ocean, then the Americas, then the broad Pacific, then Australia and Asia pass under the Day and Night Circle on the right, thus going behind the curtain of darkness, while the opposite side of the globe, they issue again into daylight, following one another in the same order. Only from such a life-like presentation of the phenomenon can a clear idea be obtained of the alternation of day and night on different parts of the earth.

Observe, too, that just as the noon line lies straight north and south, i. e. **from pole to pole**, on the earth's surface, and at right angles to the equator, so if you look straight down upon the edge of the Day and Night Circle you see the lines of sunrise and of sunset also lying exactly north and south at right angles to the equator. We shall see later that this is not always so.

It is important that the pupils should here be taught a little scientific use of the imagination. Some of them, seeing the sun represented so small and so close to the earth, may not, without aid, clearly understand how it can illuminate at once the whole of a hemisphere of the earth, so as to be seen simultaneously by inhabitants dwelling all around the edge of the Day and Night Circle as well as by those who are directly under the central ray. They should be told that the sun is immensely larger than the earth, but also very far away, so far in fact that lines of sight directed to the sun from any and all points on the side of the earth that happens to be turned toward him, are all parallel. One way in which

the teacher can make this evident is by balancing a ruler over the top of the globe and showing that it is parallel with the central ray of the sun. Then, moving the ruler around the circumference of the Day and Night Circle, he can show that the parallelism exists at every point.

Angular Rate of the Earth's Rotation

Having observed how the eastward rotation of the earth on its axis causes the sun to travel westward around the globe, carrying sunrise, noon, and sunset with it, as if daylight were a cap covering half the globe and continually slipping around it toward the west, let us now fix our attention on the equator. Notice that it is divided (as all circles always are for mathematical purposes) into 360 equal parts, called degrees. Now, there are 24 hours in the period of one rotation of the earth, called a "day," and 360 divided by 24 gives 15; from which we see that the earth must turn in its daily rotation through 15 degrees in one hour. This is a very important fact to be committed to memory. It is with reference to this fact that the meridians of longitude are drawn on the globe at intervals of 15 degrees. If we set the sun over any one of these meridians and then rotate the globe until the next meridian westward comes under the sun we shall have turned the globe just as far, angularly, as the earth turns in one hour. And, since there are 60 minutes in an hour, and it takes the earth an hour to turn 15 degrees, if we rotate the globe only one degree we shall have turned it as far as the real earth turns in 4 minutes. This is another most important fact to be always carried in the memory, viz. that in every four minutes of time the earth turns one degree eastward around its axis, while during the same time the sun appears to move one degree westward through the sky. We shall have frequent occasion to use this while working with the semi-tellurian.

THE SUN'S YEARLY MOTION—THE SEASONS

We next consider the ecliptic, or the sun's yearly path. This, as we have already seen, is drawn upon the globe, crossing the equator at two opposite points. For convenience it is represented as if it lay upon the earth instead of running around the background of the sky. Now, just as the division of the equator into degrees enables us to measure the

angular distance that the earth rotates during any given time, as one hour, or four minutes, so the divisions that we see on the ecliptic enable us to measure the distance that the sun advances during a given time in its yearly course around the earth. But on the ecliptic each division marks not one degree but one day. So we see that the earth makes one rotation (through 360 degrees) while the sun is going forward about one degree on the ecliptic. The correspondence would be exact if the year were just 360 days long.

Observe that as the ecliptic is drawn on the globe, the 1st of January falls at a point off the west coast of South America, but the sun's yearly journey is assumed to begin on March 21, which, in order to bring the astronomical and geographical prime meridians into accord, is represented on the globe as lying on the meridian of Greenwich at the point where the equator and the ecliptic meet



Position of Earth March 21st.
Vernal Equinox.

and cross, and where we placed the sun when we were observing the sun's daily motion, and the succession of day and night.

This point on the ecliptic which the sun reaches every year about March 21 is called the Vernal Equinox, and the meridian running north and south through it is the equinoctial colure, or Prime meridian of the heavens. The meridian of the earth which corresponds to it, and passes through Greenwich, is called the Prime meridian of the earth. Longitude and time are reckoned from that meridian.

Now, what we want first to show is how the sun advances eastward in the ecliptic, making a complete round in a year, and how, as it ad-

vances, its position with reference to the equator continually changes. We begin by fixing the sun, as we did before, with its central ray over the point marked March 21 on the ecliptic and 0 degrees on the equator. Set the globe before you in such a way that the north pole of the axis inclines toward the right. Then the ecliptic will lie in a horizontal position.

The sun is now at the point in the ecliptic which it occupies at the beginning of the astronomical spring. It is vertical over the equator, and as we shall see more fully later, day and night are now of equal length all over the earth. This is the origin of the word equinox.

Without rotating the earth on its axis, advance the sun along the ecliptic toward the east by pushing it together with the Day and Night Circle around toward the right, for you will observe that the dates marked on the ecliptic run that way.

As soon as the sun is moved it leaves the equator and begins to approach gradually toward the north pole in consequence of the inclination of the ecliptic to the equator. By April 1 it is several degrees north of the equator. As we continue to push it eastward it glides yet farther from the equator and nearer to the north pole, until, when it has arrived over the date June 22, it is $23\frac{1}{2}$ degrees north of the equator, and only $66\frac{1}{2}$ degrees south of the pole. This is as far north as it can go, since its motions are confined to the ecliptic, and this point is called the Summer solstice, because the ancients noticed that,

at this time of the year the sun seems for a considerable period to return to about the same elevation in the sky at each successive noon. Solstice comes from the Latin words meaning "sun standing." The Globe shows that for some distance on either side of June 22 the sun's distance from the equator varies but slightly, because the ecliptic there runs nearly parallel with the equator.

Now, if we continue to push the sun-ball around eastward, after leaving June 22 we see it decline again toward the equator, and on Sept. 23 it once more crosses the equator, this time trending southward. Thus it returns to the southern hemisphere from which it emerged six months



Position of Earth June 22nd.
Summer Solstice.

before at the Vernal equinox. The point where the sun crosses the equator on Sept. 23 is called the Autumnal equinox, because then again day and night are of equal length all over the earth.

But we must follow the sun still farther for as yet we have seen it perform only half of its yearly course. We keep on, then, pushing it around the ecliptic, being careful not to rotate the globe, and it moves farther and farther south of the equator, and nearer and nearer to the south pole, until, on Dec. 22, it reaches its farthest southern position, $23\frac{1}{2}$ degrees below the equator, and there arrives at the Winter solstice, exactly resembling the Summer solstice except that it occurs when the sun is as far south of the equator as it can go, while the Summer solstice occurs when it is as far north as it can go. But for people who live south of the equator our Winter solstice is their Summer solstice and vice versa.

To complete the sun's yearly journey around the ecliptic we push it on eastward from Dec. 22, watching it now approach again toward the equator until on March 21, one year after its start, it once more reaches the equator at the Vernal equinox, and mounts again into the northern hemisphere, bringing back spring and summer in its train.

Now, this alternate northward and southward gliding of the sun with respect to the equator is due entirely to the inclined position of the earth's axis. A very striking proof of this is obtained if we look at the situation of the earth's poles when the sun is at March 21. Then both poles are seen to be under the Day and Night Circle, but inclined $23\frac{1}{2}$ degrees from the central points at the top and bottom of the Circle. Those points represent the poles of the ecliptic, as if that, too, had an axis running through its center at right angles to its plane. Now push the sun around to June 22; then the north pole projects out of the Day and Night Circle $23\frac{1}{2}$ degrees toward the sun, while the south pole projects an equal distance away from the sun. Put the sun at Dec. 22, and it is the south pole that projects toward the sun and the north pole away from it. Thus it is evident that the ecliptic circle is like an equator for the poles of the ecliptic, and that since in its yearly motion the sun always remains in the plane of the ecliptic circle, it is compelled to be six months above and six months below the plane of the earth's equator.

Here then, plain before the eyes, is the cause of all those wonderful changes of temperature, of sunlight, of green fields succeeding blankets of snow, and of blizzards chasing close upon the heels of soft Indian summer days, which we group under the sober name of seasons, or seasonal change. If the earth's axis had stood upright to the plane of the ecliptic summer and winter would have known and kept their places, instead of driving one another to and fro across the equator, while equator and ecliptic would have been merged in a single plane.

WHY SUMMER IS HOT AND WINTER COLD

At this point attention may be called to the principal cause of the contrast of temperature between summer and winter. It is the change of inclination of the sun's rays to the surface of the earth. Start with the sun at the Summer solstice, (June 22), and rotate the earth until America is on the meridian with the sun. We see that at this time the United States lie, so to speak, full face toward the sun, and the solar rays descend almost perpendicularly upon the southern point of Florida, and the mouth of the Rio Grande. When the sun's rays fall at so small an inclination more of them are received on a given amount of surface and the heat is proportionally intense.

But now advance the sun to Sept. 23 (the Autumnal equinox) and rotate the earth until America is on the meridian, and you find that, as seen from the direction of the sun, the surface of the United States is very much more inclined to the solar rays falling upon it than was the case on June 22, and consequently those rays are less effective than they were three months before, so that the cooler days of Autumn now approach.

Next push the sun on to Dec. 22 (the Winter solstice), and observe, when America is on the meridian, that the northern part of the United States seems to lie away over the shoulder of the earth, sloping away from the sun, so that the rays now fall at a low angle, even on the southern states, and consequently are much less effective for heating and lighting than they were even in September, and still less than they were in June. Now is the season of the snows. In the meantime South America has moved up, as it were, right under the sun, and southern Africa, and Australia, as can be seen by rotating the globe, are now having their hottest weather.



Position of Earth Sept. 23rd.
Autumnal Equinox.

THE SUN'S TWO MOTIONS COMBINED

Heretofore we have been studying **separately** the two motions of the sun—the daily and the yearly,—now let us consider the effects of their **combination**, for of course they both go on together. If the earth simply travelled around the sun, with its axis inclined as it now is, but without rotating, there would be but one day and one night in a year, and every place on the earth would have six months of daylight fol-

lowed by six months of darkness. Then if the sun could draw a continuous photographic line on the earth as the earth went around him that line would coincide with the ecliptic circle drawn around the Globe. But the daily rotation of the earth changes this so that the single photographic line would be spread into a band of close-packed spirals covering all the space between the Tropics, as the sun winds its way now northward and now southward.

But for our purposes we may imagine the sun as remaining during each successive day at an unvarying distance from the equator, i. e. with its declination fixed during 24 hours.

We start with the sun on the Prime meridian, at March 21, or the Vernal equinox. Now, keeping the sun fixed in position and, before rotating the globe, observe again what we saw in a former demonstration, viz. the hemispherical cap of daylight extending from the sun's central



Position of Earth Dec. 22nd.
Winter Solstice.

ray 90 degrees in every direction, north, south, east, and west, until its border is formed by the Day and Night Circle. Notice that the Day and Night Circle passes over both poles, and cuts the equator at right angles on both sides. Since both poles are on this line between day and night, both are reached, at the same time, by the sun's rays—just reached and no more, for as seen from either pole the sun would now appear to lie on the horizon.

(Either at this point or later, the teacher may explain the effects of twilight and atmospheric refraction, to which we shall devote a few words further on).

Now, leaving the sun fixed in position, rotate the globe on its axis from west to east. The sun follows the equator westward, crossing the meridians one after another as they move eastward under him. Observe that as each meridian passes under the Day and Night Circle it is parallel with that Circle. While the globe is rotating place yourself in imagina-



Position of Earth March 21st.
Vernal Equinox.

tion standing on either the north or the south pole. You see that you could have one foot on the daylight side and the other on the night side of the line between day and night (if that were a perfectly sharp line), so that as the earth turned, you would see the sun apparently running around you on the horizon, with half of its disk above and the other half below.

THE TIME OF EQUAL DAYS AND NIGHTS

But here is a thing of more practical importance to everybody. Notice that as the earth rotates, with the sun in the position that it occupies on March 21, day and night are of equal length everywhere on the globe. This is evident because, as you can see by looking straight down upon the edge of the Day and Night Circle, the line between day and night cuts every parallel of latitude from the equator to both poles exactly in half. This being so, and every place on the globe being carried around on its own parallel of latitude as the earth rotates, every such place must be half of the 24 hours in the daylight and the other half in the night.

But it is instructive to demonstrate this by actually rotating the globe. Take, to begin with a place on the equator. Let it be Quito in South America. Without moving the sun, turn the globe until Quito is exactly under the sunrise (left-hand) edge of the Day and Night Circle. Then place the Quadrant on the meridian of Greenwich, with its arrow pointing to 0 degrees on the equator, and tighten the screw at the north pole to hold the Quadrant firmly in position. Next rotate the globe from west to east until Quito comes under the sunset (right-hand), edge of the Day and Night Circle. Now count along the equator the number of degrees that the point of the Quadrant has passed over, moving westward from the Greenwich meridian. You will find that the distance moved is 180 degrees, or just one-half way round the globe, i. e. one half of a complete rotation of the earth. But since a whole rotation takes 24 hours it is evident that half a rotation must take 12 hours, from which we see that at the Vernal equinox, the length of the day at Quito, on the equator, is 12 hours, leaving 12 hours for the night. If we try the same experiment with any other place lying on the equator we get the same result.

This demonstrates that all around the equator on March 21, day and night are of equal length; but are they of equal length at all other points on the earth? Yes, and to prove it let us take Chicago, which is almost 42 degrees north of the equator. Place Chicago under the sunrise edge of the Day and Night Circle, then set the Quadrant pointing to 0 degrees on the equator, rotate the globe eastward until Chicago comes under the sunset edge, and count the number of degrees that the Quadrant has moved westward. It is again 180 degrees, showing that the earth has rotated just half way round in carrying Chicago from the sunrise to the sunset, so that the day must be 12 hours long at Chicago, just as it is at Quito. If you repeat the demonstration for any other place, anywhere on the globe, you get precisely the same result.

Notice one other thing and remember it for comparison afterward; since the meridians as they pass under the Day and Night Circle are all parallel with that Circle, it is evident that at the time of the equinox all places lying on the same meridian of longitude, i. e. the same north-and-south line, must have sunrise and sunset, and also noon, at the same absolute time.

To finish with the study of what happens when the sun is vertical over the equator, fix the sun over the date Sept. 23 (the Autumnal equinox), and repeat the demonstrations above described, observing that the same results are obtained as to the equality of day and night everywhere, and that, just as at the Vernal equinox, daylight extends from pole to pole. But remember that this condition exists only at the two equinoxes, for at all other times of the year, **except exactly on the equator**, day and night are unequal.

Unequal Days and Nights

We shall now study the phenomena and causes of days and nights unequal in length. It will be recalled that, when we were considering the yearly march of the sun around the ecliptic, we found that after March 21 it began to depart northward from the equator, arriving on June 22 at its farthest northern declination, $23\frac{1}{2}$ degrees. Let us now place the sun at June 22 on the ecliptic. (You will find the point marked on the globe near Calcutta, India). Now you see the north pole leaning toward the sun, the consequence of which as affecting the temperature we have already pointed out.

Rotate the globe on its axis and not only the north pole, but a great circular area around it, covering more than eight million square miles, the south border of which is indicated by a dotted circle $23\frac{1}{2}$ degrees from the pole, marked "Arctic Circle," remains wholly and constantly in the sunlight, while the south pole is surrounded by a similar circle, the "Antarctic Circle," within which, as the globe rotates, the sun does not rise at all.

WONDERFUL PHENOMENA AT THE POLES

The north pole is now in the middle of a period of six months during which the sun never sets upon it, while the south pole is in the middle of a similar period during which the sun never rises upon it. Imagine yourself again standing on the north pole. Any direction that you choose to look over the earth's surface is south. The whole earth lies south of you. The circle of the horizon as it runs around you is everywhere south of your position. If there is any north at all for you it is directly over your head, in the zenith. West and east are directions indicated only by the way you are turning on a vertical axis with the earth's rotation.

The sun appears $23\frac{1}{2}$ degrees above the horizon, slowly circling around you from east to west but keeping at the same elevation. That is one way in which an explorer can tell when he is on the pole. If you set up a stake in front of you, and in line with the sun and keep facing the stake, then in 24 hours the sun will have gone all around the sky behind you and come back into line with the stake. (Of course it is you and the stake that have really been in rotation).

Now imagine yourself starting from the pole and walking straight south along any meridian. As you go on, the circle that the sun describes in 24 hours will be tipped more and more to the plane of the horizon. You will again have a direction north—the direction of the pole—and when you have gone say 10 degrees from the pole, or nearly 700 miles, the sun's circle of revolution in the sky will be elevated about $33\frac{1}{2}$ degrees above the horizon directly in the south, but only about $13\frac{1}{2}$ degrees above it directly in the north. Keep on until you reach the Arctic Circle. Then, when the sun is south, it will be 47 degrees above the horizon, and when it is north it will lie right on the horizon.

This is the celebrated phenomenon of the "Midnight Sun," which is visible at the time of the Summer solstice, in Norway and Alaska, and, in fact, anywhere around the Arctic Circle. The name comes from the fact that it is midnight at all points south of the Arctic Circle at the moment when, on or near that Circle, the sun just touches the northern horizon.

But if at the Summer Solstice you started from the **south** pole, you would walk in darkness until you reached the Antarctic Circle, and there, when the sun was exactly north it would just come up for a moment to the horizon, like a fish timidly touching the water surface from below, and then sink out of sight.

(In these illustrations the declination of the sun is supposed to remain unchanged while the observer is changing his position).

DAY AND NIGHT INSIDE THE POLAR CIRCLES

The Costello Globe affords an admirably graphic means of illustrating the way in which the Arctic and Antarctic nights and days lengthen between equinox and solstice, and shorten between solstice and equinox, while the area around the pole within which the sunlight or darkness is continuous for a certain period, alternately expands and contracts. For this purpose, start again with the sun placed over March 21, and the **north pole inclining toward the right so that the ecliptic will lie horizontal.**

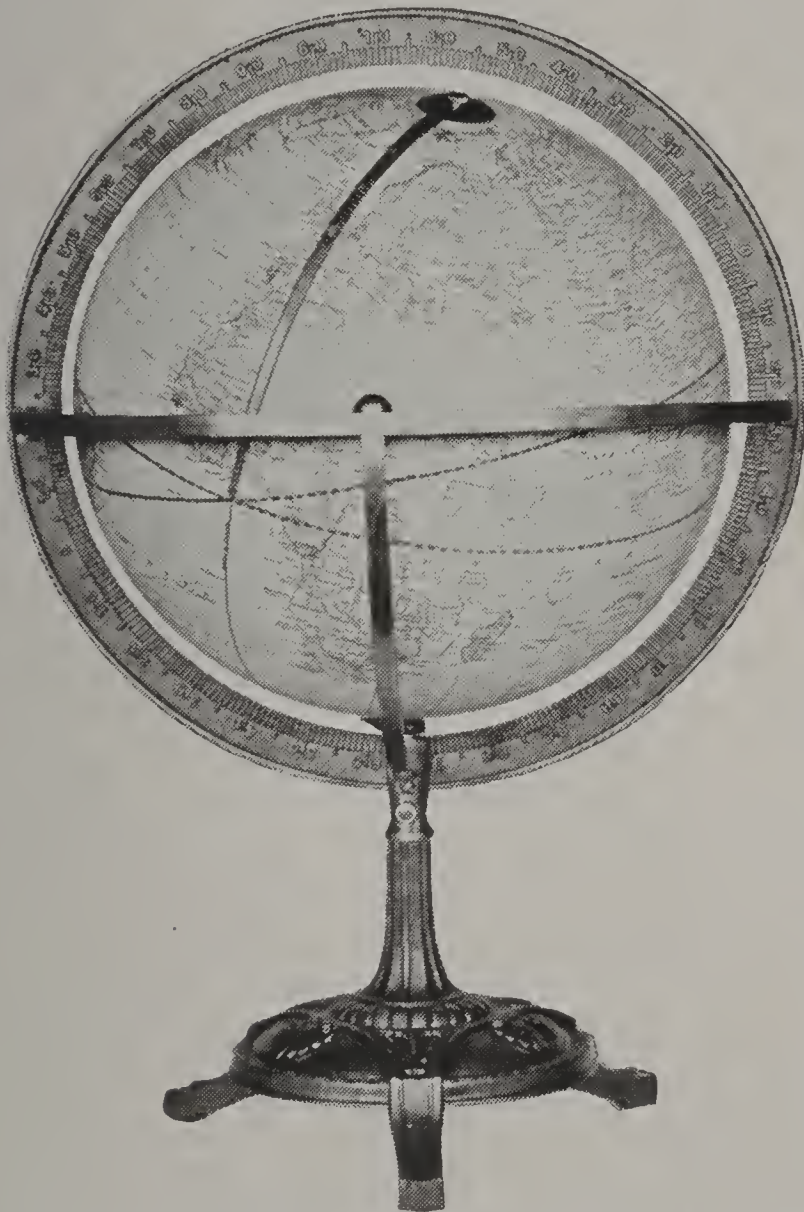
Then stand in such a position that you can look down upon the north pole, and, without rotating the earth, push the sun around the ecliptic toward the east. You will see the Day and Night Circle move away from the pole and approach the Arctic Circle, while the pole passes out into full sunlight, and around it expands an ever widening circular area lying, like the pole, entirely inside the sunrise line. This will continue until the sun is over June 22, the Summer solstice, when the Day and Night Circle will have receded away $23\frac{1}{2}$ degrees from the pole and will lie tangent to the Arctic Circle. At that moment it is evidently perpetual day everywhere within the Arctic Circle.

But continue to push the sun around the ecliptic eastward, and quickly you will see that the Day and Night Circle is returning poleward, so that it is no longer perpetual day on the Arctic Circle, and the circular area covered by perpetual day will grow smaller until the sun reaches Sept. 23, when again the Day and Night Circle lies over both poles, and day and night are equal all over the earth.

Keeping on after Sept. 23 the Day and Night Circle will be seen retreating again from the north pole but this time in such a direction as to cause the pole to move into the night side and to go deeper and deeper, until Dec. 22 when the night area has spread as far out as the Arctic Circle. (The teacher may add many details to this illuminating demonstration which will increase its interest to the pupils).

DAY AND NIGHT BETWEEN THE EQUATOR AND THE POLAR CIRCLES

Now, having seen what the phenomena of day and night are around the poles at the Summer solstice, let us examine the conditions at that same time on the other parts of the earth. Place the sun back over June 22. Rotate the earth from west to east, and the sun, keeping $23\frac{1}{2}$ degrees north of the equator, runs around the earth, following a dotted line marked "Tropic of Cancer."



Position of Earth June 22 with Chicago under the Sunrise Line and the quadrant set on the meridian of Greenwich.

Starting from Calcutta in India, it passes over the center of Arabia, the desert of Sahara, the Central Atlantic, the Gulf of Mexico, the Pacific ocean, southern China, and so back to Calcutta. All along that line, on June 22, the sun is vertical, or in the zenith. (It is not quite vertical throughout the circuit, because its declination is slowly changing, but we neglect this). To all the inhabitants of the earth south of the Tropic of Cancer the sun, at noon, appears **north** of the zenith, and farther north in proportion as they are farther south; while to all the inhabitants north of the Tropic of Cancer, the noon sun is **south** of the zenith, and farther south as they are farther north. Observe that just as far as the Tropic of Cancer is north of the equator so far does the daylight extend beyond the north pole, on the side away from the sun.

To see the effects of this on the length of day and night, let us go back to Chicago, which is about 18 degrees north of the Tropic of Cancer. We put Chicago under the sunrise line, set the Quadrant on the meridian of Greenwich, pointing to 0 on the equator, and rotate the globe eastward until Chicago is under the sunset line. Then we count the number of degrees that the Quadrant has swept westward on the equator, from the meridian of Greenwich, and find it to be about 226. Multiply this number of degrees by 4 to reduce it to minutes of time, and you get 904 minutes, which divided by 60 minutes to the hour, gives 15 hours and 4 minutes for the length of the day, or the length of

time that the sun remains above the horizon at Chicago on June 22. Subtracted from 24 hours, this leaves 8 hours 56 minutes for the length of the night. (The above result is a few minutes shorter than the length of the day shown by almanacs because we take no account of atmospheric refraction, whose effect is to hasten the apparent time of sunrise and delay the apparent time of sunset).

Now, compare the result that we have just obtained with that which we got when the sun was at the Vernal equinox. Then day and night at Chicago were of equal length, each being 12 hours long, but now, three months later, day is about six hours longer than night. Why is this? We can easily show why by putting Chicago again under the sunrise line, and rotating the globe eastward, while keeping the eye fixed on Chicago as it is carried around. We see that, owing to the inclination of the north pole toward the sun, the arc passed over by Chicago in traversing the daylight side of the globe is much longer than the arc that it passes over in going around through the night side. This difference is also evident if we simply fix attention upon the parallel of latitude of 40 degrees which runs around a little below Chicago, and note how much longer that part of it is which lies on the sunlit half of the globe.

If you take any other place, anywhere on the same parallel of latitude with Chicago, no matter how far east or how far west it may be, you will find the same length of day and night as at Chicago. But if you take a place lying either farther north or farther south than Chicago you find a different length of day. It will be longer if the place is farther north, and shorter if the place is farther south. This, like the equality of day and night at the equinox, is evident by inspection, for if now again we look down upon the edge of the Day and Night Circle we see that it cuts all the parallels of latitude into two unequal parts, the longer part, or arc, lying on the daylight side and the farther north we go the more the daylight arc exceeds the night arc in length. If we go as far as the Arctic Circle we find that the Day and Night Circle does not cut that at all, but leaves it entirely on the daylight side.



Position of Earth June 22nd with Chicago under the Sunset Line with quadrant on the 134th degree East.

However, as in the other case, it is instructive and interesting to demonstrate this inequality by rotating the globe under the solstitial sun. For this purpose take Juneau in Alaska, and rotate it, as we did Chicago, from sunrise to sunset (always setting the Quadrant anew on the Greenwich meridian for every new place that we try), and we find that the Quadrant turns through $262\frac{1}{2}$ degrees, which reduced to time gives 17 hours 30 minutes for the length of day at Juneau when it is 15 hours 4 minutes at Chicago. Going still farther north, to the Arctic Circle, we find that there, day becomes 24 hours long, and night, **for that one date**, vanishes.

Then, going in the other direction, try the city of Mexico, more than 20 degrees south of Chicago, and you find that its day is only 13 hours 12 minutes, when Chicago's is 15 hours 4 minutes. And if you keep on going south until you reach the equator, you find that the day shortens and shortens until, just on the equator, it becomes again exactly equal in length to the night—12 hours each. Thus at Quito, or at any other point on the equator, day and night are equal at all times of the year, while for other parts of the earth they are equal only at two opposite times in the year, viz. the Vernal and the Autumnal equinox.

In general, if we fix attention on any one particular **place** (not situated on the equator) we find that its days lengthen and its nights shorten as long as the sun is rising higher above the equator, but when the sun is sinking the days shorten and the nights lengthen. On the other hand, if we shift the place and fix attention on some particular **date** (excepting the two equinoxes) the length of the day increases as the latitude of the place is greater and decreases as the latitude is less.

In our demonstrations we have dealt only with the northern hemisphere, but precisely similar results will be obtained for places south of the equator, except that when the days are longer than the nights in one hemisphere they are proportionally shorter than the nights in the opposite hemisphere.

In making these demonstrations it is not necessary to choose only the dates of the equinoxes or the solstices; they show the extreme conditions, but any other time of the year may be taken. For a single illustrative instance, take Aug. 15, and let the place be Chicago. Fix the sun over the date Aug. 15 on the ecliptic, and then proceed as in the other cases. We thus find that the length of the day at Chicago in mid-August has become only 13 hours 44 minutes. You may make a similar demonstration for any place, on any date. (Never forget to set the Quadrant on the Greenwich meridian **after** putting the chosen place on the sunrise line).

THE TIMES OF SUNRISE AND SUNSET—AT THE EQUINOXES

We now come to the question of telling the hours of sunrise and sunset, which the Costello Globe enables us to solve with the greatest ease.

We begin once more at one of the equinoxes—say the Vernal. We set the sun over the date March 21, and we take a place on the equator, say Quito, and bring it under the sunrise line; then we set the Quadrant pointing to 0 degrees on the equator (meridian of Greenwich), after which we rotate the globe eastward until Quito comes vertically under the central ray of the sun-ball. This means that Quito has passed from sunrise to noon, and now has the sun in its zenith. Counting the number of degrees that the Quadrant has swept westward on the equator we find that it is just 90, which corresponds to six hours of time. So we see that at a place on the equator, at the time of the equinox, the sun rises six hours before noon, i. e. at six o'clock A. M. (It should be remarked that we are referring throughout this manual not to "standard time," or "daylight saving" time, but to local solar time). If we continue the earth's rotation until Quito reaches the sunset line, we shall find that the sun sets there six hours after noon, or at six o'clock P. M.

So much for the hours of sunrise and sunset for places on the equator. (Stanleyville in the middle of Africa is another place on the equator that you might try). Now let us go north to Chicago. We place Chicago under the sunrise, reset the Quadrant, and rotate the globe until Chicago is on the **noon line**, which means the meridian, or north-and-south line, running under the central ray of the sun-ball. It was easy to bring Quito to the noon line because the place came right under the sun, and if the meridian running through Chicago were marked on the globe it would be equally easy to bring Chicago to the noon line simply by carrying its meridian under the center of the sun. As it happens,



Position of Earth March 21st with Chicago under the Sun's noon ray and the quadrant on the 90th meridian West.

however, Chicago is more than two degrees east of the 90th meridian marked on the globe, and since the distance between the meridians increases as the latitude decreases, it is necessary to use a little care and judgment in placing Chicago on the same meridian, with the sun. Having placed it so, we again count the degrees that the Quadrant has moved on the equator, and find the number to be again 90, just as it was for Quito. This proves that, at the equinoxes sunrise occurs everywhere on the earth at six o'clock A. M. and sunset at six o'clock P. M., corresponding with the equality in the length of day and night at the equinoxes, which we demonstrated before.

At the Solstices



Position of Earth June 22nd with Chicago under the Sun's noon ray and the quadrant on the 113th degree West.

Next let us see what happens at the solstices—say the Summer solstice, which occurs June 22, when the sun is vertical along the circle of the Tropic of Cancer, $23\frac{1}{2}$ degrees north of the equator. If, with the sun placed over the date June 22, we repeat with Chicago what we did at the equinox we find that, in carrying Chicago from the sunrise to the noon line the earth turns about 113 degrees on its axis, corresponding to 452 minutes of time, or 7 hours 32 minutes. Remark that this is the length of time that elapses between sunrise and noon, and to find out what the time of sunrise shown on the dial of a clock keeping local time is, we must subtract the 7 hours 32 minutes from 12, the number of hours between midnight and noon. The subtraction leaves 4 hours 28 minutes, which is the sunrise time. (This makes no allowance for atmospheric refraction, or other corrections).

To find the time of sunset we have only to reverse the subtraction that we made before by taking the sunrise time from 12 hours; or we can use the figures found at first for the number of hours between sunrise and noon, because these represent also the number of hours between noon and sunset. (If we were seeking very exact results we would have to allow for the hourly movement of the sun in the ecliptic). If it is desired to find the time of sunset directly, it can be done by starting with Chicago on the noon line, with the Quadrant fixed at 0 degrees, rotating

the globe until Chicago is under the sunset line, and then, as before, counting the degrees passed over by the Quadrant. Reducing these to time gives the time of sunset without any subtraction.

Note that for any other place lying on the same parallel of latitude the times of sunrise and sunset are the same as at Chicago. But north of Chicago the sun rises earlier and sets later than at Chicago, while south of Chicago the sunrise occurs later and the sunset earlier.

We have before noticed that at the equinoxes the sunrise and sunset line lie parallel with the meridians of the earth, and at right angles to the equator. This is not the case at any other time of the year, (although it is always true of the noon line), and the variation is greatest at the solstices. It is this that causes the difference in sunrise and sunset times between places having different latitudes. A very interesting effect is seen by placing for instance Chicago on the sunrise line at the time of the Summer solstice, and observing the sloping direction which that line takes in crossing the United States. Instead of running north and south it runs from the western end of Lake Superior through Chicago, through central Indiana, passing near Louisville, Ky., and so on, south-eastward, until it emerges into the ocean between Savannah and Charleston and thence goes on across the Bahama islands. All along that line early risers see the sun coming up at practically the same moment that it is seen at Chicago. But they do not all see it crossing the meridian at the same time, as you can prove by putting Chicago at noon, and noting the direction of the noon line.

And now see how very different the situation becomes at sunset. Put Chicago on the sunset line, and observe that its course across the United States is from Sault Ste Marie through Chicago, St. Louis, the south-western corner of Arkansas, eastern Texas, crossing into Mexico above the mouth of the Rio Grande and passing not far west of Mexico City, and so out across the Pacific ocean. All along that line people see the sun set at practically the same moment as at Chicago. But what a different company it is from that which lined up to see the sun rise!

At the equinoxes the line runs exactly north and south, (as it always does, everywhere, at noon), and New Orleans and Chicago see the sun both rise and set at nearly the same time, but when we go on to the Winter solstice (Dec. 22) we get the lines of sunrise and sunset crossing again, only this time their directions are exactly reversed, the sunrise line running south-west from Chicago and the sunset line south-east.

REFRACTION

The gaseous atmosphere surrounding the earth and consisting mainly of a mixture of oxygen and hydrogen, possesses like all transparent media the power to refract, or bend out of their original course, rays of light passing into and through it. The refraction increases with the density of the air, and consequently is greater with rays passing through the lower and denser layers of the atmosphere than with those which pass only through the rarer layers overhead. Directly in the zenith there is no refraction, but as the horizon is approached the refraction increases nearly as the tangent of the angular distance from the zenith. Just at the horizon the amount of the refraction becomes, on the average, a little more than half a degree, but it varies more or less with the changing density and temperature of the air. Now, the refraction acts in a vertical direction, so that the rays of light coming from a distant body close to the horizon are bent downward between the object and the observer's eye, the effect being that the object appears to be lifted higher above the horizon than it really is. Since the angular diameter of the sun is about half a degree (the same as the amount of the refraction) it is evident that the refraction is capable of lifting the sun into view after it has really just sunk beneath the horizon. So, under ordinary circumstances, in a fairly level country, when you see the sun apparently resting with its lower rim on the horizon it is really wholly below with its upper rim only reaching the level of the horizon. Now, the daily motion of the sun, as we have before seen, carries it westward about one degree in four minutes; hence two minutes are required for the sun to move its own diameter, so that when the sun is setting the refraction adds two minutes to the length of the afternoon. Conversely the refraction causes the sun to appear above the eastern horizon two minutes before its real rising; thus on the whole four minutes are added to the length of the daylight period, **at the equator**, where the sun rises and sets vertically, but the farther you go from the equator the more slopingly to the horizon does the path of the sun lie, and the longer the sun takes to rise and set, so that the refraction lengthens the day least at the equator and most in high latitudes. The lengthening effect also varies at a given place with the position of the sun in the ecliptic. In middle latitudes it varies from four to eight minutes. Another curious optical effect of refraction is to cause the disk of the sun (and also of the moon) to appear distorted when near the rising or setting point, the lower edge of the disk being lifted more than the upper edge so that it seems to be flattened in a vertical direction, or stretched out horizontally.

TWILIGHT

Another atmospheric phenomenon which affects the length of time during which illumination from the sun reaches a given place on the earth is twilight, which is visible both after sunset and before sunrise. The morning twilight is usually called dawn. Twilight is due to the illumination of the higher layers of the atmosphere up to the level where the air becomes so rare that no perceptible reflection of light is perceived from it. This is about 40 miles above sea-level, under average circumstances, and the twilight does not wholly disappear until the sun has descended about 18 degrees below the horizon. That requires about an hour and a quarter, but where the sun's path lies slopingly to the horizon, the duration of twilight is increased. In middle latitudes it is stretched out to about two hours in mid-summer. On the equator the duration is at a minimum because there the sun rises and sets vertically. Immediately after sunset, or immediately before sunrise, the twilight is almost as bright as moderate daylight, and for an hour or more in summer evenings daylight occupations may be continued in the gradually cooling and darkening air. The morning twilight is more stimulating if not more refreshing. It is a blessing that we owe entirely to the atmosphere. There can be no twilight on the moon.



A remarkable effect of twilight is seen in the polar regions, where the illumination of the sky before sunrise and after sunset adds weeks of partial daylight to the long Arctic and Antarctic days. This is clearly demonstrated by the Costello Globe. First place the Globe before you with the sun at the Autumnal equinox, (Sept. 23) with the north pole inclined, this time, to the left. The plane of the ecliptic will be horizontal. The pole is now under the Day and Night Circle. But move the sun eastward on the ecliptic and immediately the line between day and night begins to swerve away from the pole, leaving it in darkness. It is the beginning of the long polar night (the effect of such a demonstration is much heightened if the Globe is placed near a window, with the night

side of the Day and Night Circle kept in shadow). Owing to refraction the sun will probably not set at the pole before about Sept. 25. Keep on moving the sun eastward, and the pole sinks deeper into the night. But remember that twilight lasts until the sun is 18 degrees from the horizon. Continue, then, to push the sun eastward until the Day and Night Circle has retreated 18 degrees from the pole. You can measure the distance by setting the Quadrant in line with the sun, and counting its graduations. Thus you will find that, when the sun is 18 degrees below the horizon of the pole, i. e. 18 degrees below the equator, it is near the date Nov. 14. This means that evening twilight at the pole has lasted from Sept. 25 to Nov. 14, a period of 50 days, instead of lasting only an hour or two as it does in the middle latitudes.

Moreover if you trace the course of the sun back again through the succeeding months you find that after having sunk $23\frac{1}{2}$ degrees below the polar horizon and the equator, on Dec. 22, it returns to only 18 degrees below at the end of January leaving another period of about 50 days before it rises on the pole at, or a little ahead of, the Vernal Equinox. This is the north pole's morning twilight or dawn. Putting the two together we get about 100 days of twilight at the pole, which makes daylight and twilight together last 280 days leaving only 80 days, or less than three months, for the yearly duration of nocturnal darkness. This shows that as far as the total duration of light in a year is concerned the poles are favored above all other places on the earth.

PRECESSION OF THE EQUINOXES

The inclination of the earth's axis from a perpendicular to the plane of the ecliptic is so important in its effects that the facts concerning it need to be presented a little more fully than they have appeared in the demonstrations thus far described. The future of the inhabited globe is deeply concerned in a fact which we have not hitherto mentioned, viz. that the **direction in space** of the inclined axis of the earth is **slowly changing**. The result of this change is that in a period of about 25,800 years the north pole, (we need consider but one of the poles though both are similarly affected), makes a revolution around the north pole of the ecliptic in a circle of $23\frac{1}{2}$ degrees radius. At the present time the north pole points very nearly toward the star known as Polaris, or the "North Star;" but 12,500 years hence it will point about 47 degrees away from that star, and within a few degrees of the very brilliant star Vega in the constellation Lyra. This revolution of the poles of the equator around the axis of the ecliptic, is known as the Precession of the Equinoxes, because an important consequence of it is that the crossing points of the equator and the ecliptic slowly shift around westward, and in 12,500 years the Vernal equinox will be where the Autumnal equinox is now. But the yearly change is very slight, amounting to about $1/72$ of a degree, or 50 seconds-of-arc. The cause of the Precession is the attraction of the sun and moon upon the protuberant equatorial part of the earth, which is slightly swelled at the equator and drawn in at the poles. The result is a gyroscopic motion of the rotating earth recalling the revolution of the peg of a top that is spinning with its axis inclined instead of upright. The angle of slope of the earth's axis remains almost constant while the direction in which the axis points swings around.

Now, in order to understand the most important effect of the Precession it is necessary to remember that the earth's path, or orbit, around the sun is not an exact circle but a slightly eccentric ellipse, so that the sun being situated in one of the two foci of the ellipse, is farther from one end of the ellipse than from the other. The average distance of the earth from the sun being 93,000,000 miles, it is about three million miles nearer the sun when at the near end of its orbit, called Perihelion, than when at the far end and called Aphelion. But, owing to causes explained in works on astronomy, the **orbit itself** has a revolutionary movement which causes the Perihelion and Aphelion points to travel around **eastward** in a period of about 108,000 years. Now, it so happens that at the present time the straight line, called the Line of Apsides, joining the Perihelion and Aphelion points, nearly coincides in direction with the line joining the Summer and the Winter solstice, **and that the earth is at the Summer solstice when she is also near the Aphelion point, and at the Winter Solstice when she is near the Perihelion point.** Thus, at the present time, we get our summer when the sun is most distant, and our winter when the sun is nearest. This causes the summer to be less hot and the winter to be less cold than would be the case if the winter oc-

curred in Aphelion and the summer in Perihelion. But, owing to a combination of the effects of the Precession of the equinoxes, and the Revolution of the line of apsides, in about 10,500 years from now **the conditions will be reversed**, and then the earth will be in Aphelion in winter, and in Perihelion in summer. Moreover, since the earth travels slower when far from the sun than when near, the period from the Vernal to the Autumnal equinox is about a week longer than that from the Autumnal equinox back to the Vernal. This gives us at present a summer half of the year longer than the winter half. But ten thousand years from now the winter will be both colder and longer and the summer shorter, though hotter, than at the present time. It has been inferred that the consequence of such changes may be the occurrence of a very cold, or semi-glacial, period in the northern hemisphere. Of course the very conditions that we have been describing exist now in the southern hemisphere, but it is thought that the climatic excesses that they would otherwise produce are mitigated or avoided by the presence in that hemisphere of vast oceanic expanses greatly exceeding those of the northern hemisphere which is a land hemisphere. The characteristic of an oceanic climate is relative mildness and equality.

THE SUN

The sun is a star, but we are so much nearer to it than to any of the other stars that while they appear as mere points of light, the sun appears as an immense blazing white ball about half a degree in diameter, and so bright that when it is above the horizon it makes daylight on the earth, and when it is out of sight below the horizon we are buried in the night in spite of the twinkling of those far-off other suns, the stars. Put the sun as far away as they are and it, too, would be but a twinkling point.

Although the sun appears to be only a little more than half a degree in diameter, seen from the earth, 93,000,000 miles away, yet it is in reality about 866,000 miles in diameter while the diameter of the earth is only 8000. (The diameter of the star Betelgeuse in Orion has recently been found by measurement with the interferometer to be 300 times the sun's, or about 260,000,000 miles!)

The sun is globular in shape like the earth, but it would take more than twelve hundred thousand earths rolled into one to make a globe as large as the sun. The surface of the sun is not solid and cool like that of the earth, but the whole body of the sun is a mass of intensely heated gaseous matter comprising, it is probable, all of the chemical substances, solid, liquid, and gaseous, of which the earth is made up, though their condition there is far different from their condition on and in the earth. At the surface of the sun they appear to be partially cooled and condensed into incandescent clouds, but the enormous mass, or quantity of matter, in the sun causes so much pressure in its interior that, though the substances there are potentially in the gaseous state on account of the intense heat, yet they are prevented from expanding as they would do if released from the pressure. These gases include such matter as iron, which cannot become solid or even liquid there because of the heat. The heat of the sun apparently rises to a temperature of at least 10,000 degrees at its surface. It is radiated away in all directions together with the light, and so reaches the earth and the other planets, which revolve around the sun at distances varying from 360,000,000 miles for the nearest up to 2,800,000,000 for the most distant known. There are eight principal planets of which the earth is the third in distance from the sun. The largest planet Jupiter has about a thousandth part as much mass as the sun, but if all the planets are put together the sun exceeds them in mass, or in power of gravitation, not less than 750 times.

THE EARTH

The earth is the fifth planet in order of size, beginning with the largest. Venus is of almost the same size, but Mars and Mercury are much smaller. Jupiter is as much larger than the earth as the sun is larger than Jupiter. But, neither Jupiter, nor any of the other three large planets, Saturn, Uranus and Neptune, is solidified like the earth and the other small planets. The large planets all appear to be composed mainly if not entirely of matter in the gaseous or vaporous state, although they are not hot enough to shine like the sun. We know but little about the actual conditions of any of the planets except the earth.

The earth is about 8000 miles in diameter, and its surface, or "crust," consists of rocks formed by the cooling and combination of chemical elements like those that exist in the form of incandescent gases and vapor in the sun. It was once thought that the interior of the earth, below a depth of a few hundred miles at the most, was in a molten state, on account of the fact that as we go deeper in the earth we find the temperature of the rocks increasing at the average rate of one degree for every 60 to 80 feet of descent. But at present it is doubted that any considerable quantity of molten rock exists in the earth. The phenomena of earthquake waves have proved that the globe, as a whole, must be at least as rigid as steel. This state of rigidity results from the enormous pressure, which amounts, by calculation, to **45,000,000 pounds per square inch** at the earth's center!

The phenomena of hot springs and of volcanic eruptions simply show that, near the surface there may be "pockets" of molten material, while deeper the pressure is so great that all matter is held in a rigid state.

The earth travels around the sun in a slightly elliptical orbit, at a mean distance of nearly 93,000,000 miles. As we have before said its distance in summer is about three million miles greater than its distance in winter. (In the southern hemisphere it is the reverse). It rotates on its axis from west to east, the same direction in which it goes around the sun, making $365\frac{1}{4}$ turns in a year. The inclination of its axis has been dealt with elsewhere in this manual.

The surface of the earth is covered to the extent of about seven-tenths with oceans, the remaining three-tenths consisting of land.

The earth's form is not exactly globular, but is that of an oblate spheroid, i. e. flattened slightly around the poles and bulged around the equator. The diameter through the equator is 7,926 miles and through the poles 7,900 miles. This form is believed to have been impressed by the centrifugal force of its rotation in the early period when it was yet so hot as to be in a plastic condition. The form is that which would be assumed by a plastic globe of the earth's size rotating at about its present rate.

Not only does the earth revolve around the sun, but together with the sun, and the whole system of planets, it travels in a northward direction, nearly toward the bright star Vega, at a velocity of about 12 miles

per second, making more than 378,000,000 miles in a year that we are borne on through space in what, as far as appears, is virtually a straight course. If the other suns, the stars, also have planets, they are all making similar marvelous journeys, for there does not appear to be a star at rest anywhere in the universe.

THE MAGNETIC POLES

It is desirable that all pupils should clearly understand the difference between the poles of the earth's axis, or geographical poles, which are the true north and south poles, where all the meridians meet in a point at each end of the axis, and the **magnetic** north and south poles, whose locations are marked on the Globe, the north one being in North America, near the eastern end of McClintock channel, on the coast of Boothia peninsula, about 20 degrees, say 1385 miles, south of the north geographical pole; and the south one on the Antarctic continent, in Victoria Land, about 17 degrees 35 minutes, say 1220 miles, north of the south geographical pole. The magnetic poles indicate the direction in which the compass needle points, and since that direction is northerly and southerly, the magnetic poles are very commonly confused with the geographic poles. The magnetic poles have nothing to do with any of the directions used in this manual. If you were at the north pole the magnetic pole would be far south of you, while the pointing of the needle might give you a general notion of the direction in which the center of the United States lay: while if you were at the south pole the magnetic pole would lie far north of you in the direction of Australia and New Zealand.

THE EQUATION OF TIME

The measure of time for us is furnished by the rotation of the earth on its axis and its revolution around the sun. The first measures the length of the day; the second the length of the year. The sun serves as a clock-hand, apparently moving on the face of the sky, to show the rate of the earth's two motions.

Confining our attention first to the day by which, in this section, we always mean day and night, as one period, we find that although, taking the whole year round, it has a certain average, or mean, length, yet, in consequence of two causes which we shall briefly explain, it varies in length at different seasons. These variations are not due to any irregularity in the earth's rotation, but to a combination of the effects of its rotation with those of its revolution around the sun and of the inclination of its axis of rotation from a perpendicular to the plane of its orbit.

First fix in mind the fact that the length of the day as measured by the sun, (called the solar day, the one employed for all ordinary affairs), is equal to the time required by the sun to make one apparent revolution around the sky and come back again to the starting point, which is taken as the meridian, or noon line. Now, although the earth rotates at a regular rate, (and there is a kind of day, which we shall describe later, that is based on this regularity of the earth's rotation), the sun, moving in the ecliptic, comes back to the meridian sometimes earlier and at other times later, so that, evidently, its apparent motion is not regular.

The first cause of this irregular motion of the sun is the eccentricity of the earth's orbit, which causes the earth to change its distance from the sun by as much as three million miles, being nearest at Perihelion (in the beginning of January), and farthest at Aphelion (in the beginning of July). When it is nearer the sun the earth travels faster in its orbit and when it is farther from the sun it travels slower. Now, as we have before explained, the earth moving eastward around the sun causes the sun to appear to move eastward in the sky, and since the earth's rotation is also performed in an eastward direction, when it has made one complete turn with regard to space, or to the stars, which remain fixed in position, it has still to turn a little farther, and a little longer, in order to bring the meridian back under the sun, for the sun, too, has been moving eastward. The result is that when the earth's speed in its orbit is greater than the average the sun's apparent eastward motion is also more rapid, and, in consequence, the distance that the earth must turn to bring the sun back to the meridian is increased, and with it the length of the solar day.

Accordingly, since the earth is nearest the sun at the beginning of January and farthest from the sun at the beginning of July, its speed is continually decreasing from January to July, and continually increasing from July back to January. But, as we have just seen, when the earth's orbital speed is increasing the relative length of the solar days is also increasing, while when the earth's speed is decreasing the length of the days likewise decreases. The effect of the alternate increase and decrease ac-

cumulates so that the solar days, as far as this cause is concerned, are longest about the 1st of January, or at Perihelion, and shortest near the 1st of July, or at Aphelion.

But there is another cause, operating simultaneously to alternately increase and decrease the length of the solar days. This is the obliquity of the ecliptic to the equator, resulting from the inclined position of the earth's axis of rotation.

Owing to the inclination of the sun's apparent path through the sky (the ecliptic) with regard to the equator, the sun's eastward motion is slowest at the equinoxes, where it crosses the equator at an angle of $23\frac{1}{2}$ degrees, and fastest at the solstices, where it attains its greatest distance from the equator, and for a while moves almost parallel with it. It follows, then, that the obliquity of the ecliptic tends to make the solar days longest about the 1st of January, or at Perihelion, and shortens near the March 21st and Sept. 23rd (the equinoxes).

But since these two causes of variation are acting simultaneously, while their effects do not coincide in time or in amount, we find them sometimes reinforcing and at other times counteracting one another. Thus in summer the retardation of the earth's speed as it retreats from the sun tends to shorten the day, but at the same time the increased eastward movement of the sun near the solstice tends to lengthen the day, and the lengthening being greater than the shortening the final result is that in June and July the days are longer than the average. In winter the opposite case occurs, for then both causes combine to lengthen the days. On the other hand, in spring and autumn both causes combine to shorten the days. In the end it comes out that the longest day of the year occurs about Dec. 22, and the shortest about Sept. 17, and the greatest individual difference between them is 51 seconds, or about $\frac{5}{6}$ ths of a minute. Such difference, in itself, is too slight to be of importance in ordinary life, but the daily differences accumulate, now one way and now the other, for months in succession, so that at length their sum becomes noticeably great—and out of this arises the "equation of time."

It is now necessary to explain what is meant by "mean time" as contrasted with "solar time." True solar time follows the variations in length of the solar days. It is indicated by a sun-dial, which marks noon only when the sun is truly on the meridian of the place where the dial stands. But it is impracticable to make a reliable clock capable of following the vagaries of solar time, or keeping exact step with the sun. For this reason true solar time cannot be used for ordinary purposes, because we want our clocks to run regularly. But, advantage has been taken of the fact that, in the long run, taking in the whole year, the days have a certain average, or mean, length, and so a fictitious, or imaginary, sun has been invented which is assumed to move with perfect uniformity in the ecliptic, arriving at regular intervals of 24 hours on the meridian, or noon line. This is called the "mean sun," in contrast with the real or true sun, and clocks and watches are set to run to "mean time," i. e. the time of the mean sun.

But, although mean time serves excellently for ordinary affairs, nevertheless it is important for certain purposes to know how much mean solar time differs from true solar time. This difference is what is known as the equation of time. It is a correction which must be used in all exact observation of the times when astronomical phenomena occur.

The equation of time represents for every day in the year the accumulated gain or loss of the solar day with regard to its mean length, as it stands at that date. The daily figures for "apparent noon," i. e. true solar noon, are published in the "American Ephemeris and Nautical Almanac." Ordinary almanacs give them under the headings "sun fast," and "sun slow." The equation is geometrically represented by an annual curve, with two maxima, two minima, and four zero points. Expressed in words, the most important features of the equation may be stated as follows:

Four times a year, viz. April 15, June 14, Sept. 1, and Dec. 24, the sun and the clock are together, or solar time and mean time agree.

Twice a year the sun attains a maximum advance on the clock ("sun fast"), viz. May 14 and Nov. 2, the equation being 3 min. 48 seconds at the first of these dates, and 16 min. 20 sec. at the second.

Twice a year the sun attains a maximum retardation with reference to the clock, ("sun slow"), viz. Feb. 11, and July 26, the equation amounting to 14 min. 25 sec. on the first, and 6 min. 20 sec. on the second of these dates.

Owing to the periodical recurrence of leap year the dates vary slightly, but as given they are correct enough for general purposes. Exact figures for any date may be obtained from the Ephemeris.

We will now illustrate the use of the equation of time.

Observe that there are two ways in which the equation may be applied, and both ways are used, according to the kind of time which is to be corrected. You may either correct the mean time (clock time) to obtain the apparent time (sun time), or you may correct the apparent time to obtain the mean time. In both cases the amount of the equation is added, but the addition is made algebraically, because the equation is marked plus (+), or minus (—), according as it lies on one side or the other of the line of average, and these signs are reversed if the time to which the correction is to be applied is interchanged.

For instance, suppose that we wish to get the apparent time from the mean time, and suppose that the amount of the equation is 14 min. 20 sec.: If the date falls in a part of the year when the solar days are longer than the average, the sun will be slow with reference to the clock, and the equation, if the Ephemeris is calculated for mean noon, will be marked—. Then, it being 12 hours 0 min. 0 sec., i. e., noon, by the clock, when we add the equation with the minus sign, we get 11 hr. 45 m. 40 s. for the corresponding apparent time, which shows that, by the sun, the time is 14 m. 20 s. before noon; in other words the sun is slow to that extent. Or, let the date fall in a part of the year when the days are shorter than the average, and the sun is consequently fast by the clock. Say the equation is 16 m. 20 s. This will be marked +, in an Ephemeris based on mean noon, and when the addition is made we get

12 hr. 16 m. 20 s. for the apparent time, showing that, by the sun, the time is 16 m. 20 s. after noon, or the sun is fast to that extent.

But, if the correction is to be applied to the apparent time to get the corresponding mean time, at the same dates above given, then the algebraic signs must be interchanged. Then, in the first case, where the sun is slow, the equation will be marked $+$ instead of $-$, and in the second case where the sun is fast, it will be marked $-$ instead of $+$. If the pupil makes the additions with the signs changed, he will find that the result does not affect the real position of the sun with respect to the meridian, but shows it from the contrary points of view. A rule in a nutshell, avoiding the use of algebraic signs, would be: When the sun is fast the amount of the equation should be added to mean noon, or subtracted from apparent noon; when the sun is slow the amount of the equation should be subtracted from mean noon, or added to apparent noon.

This comparison of the two methods of applying the equation has been made because much confusion of mind sometimes results from the fact that some text-books represent the curve drawn one way and some the other. Moreover, it will be found that the Greenwich solar tables are based on mean noon, and those of Washington apparent noon, with corresponding change of signs.

It should be remarked that local mean time, with which we have been dealing, is not the time now usually kept by clocks and watches because these, for business reasons, are set to standard, or railroad time, which, when the locality is midway between two standard meridians throws the clock half an hour ahead or an equal amount behind, the true mean time. In addition to this, in many places, clocks and watches during a large part of each year, follow "daylight saving" time, which has the effect of throwing them an hour farther away from the true time.

Inequalities of Forenoon and Afternoon

There is an interesting effect produced by the equation of time upon the comparative length of forenoon and afternoon, which are assumed to divide the daylight period into two equal portions, one on each side of the meridian, or noon line. We habitually use mean, or clock, time to indicate noon, and although sunrise and sunset are referred to the real sun they are calculated in mean time. But, since the sun is at certain seasons ahead of the clock and at others behind it, the equation of time causes an inequality in the relative length of forenoon and afternoon, amounting to twice the equation, so that they are never of exactly the same length except on the four dates when the equation is zero. If the sun is ahead of the clock it crosses the meridian before mean noon and thus the length of the afternoon is relatively shortened. At the beginning of November this shortening amounts to about half an hour. But after Christmas the afternoon begins to get longer than the forenoon, attaining a maximum length near the middle of February. From the middle of April to the middle of June the forenoons are slightly the longer; from June 21 to Sept. 1st the afternoons again have the advantage, but early in September the forenoons gain once more, attaining their maximum length in the beginning of November.

Different Kinds of Day and of Year

It may be added that the length of the day and the length of the year, the first depending on the rate of the earth's rotation on its axis and the second on the speed of its revolution around the sun are, in themselves, practically invariable. The variations in the length of the day that we have been discussing affect only a particular kind of day, viz. the solar day, or day measured by the return of the sun to the noon line. This, which is the kind of day used for all ordinary purposes, depends, as we have seen, upon a combination of the effects of the earth's revolution with those of its rotation. Because the revolution makes the sun advance in the sky in the same direction in which the rotation occurs, the earth has to turn a trifle longer each day in order to bring the sun back again to the noon line, than it would if the sun stood fast in the sky. Accordingly, the solar day does not accord with the true period of the earth's rotation.

But there is another kind of day, used by astronomers, which does accord with the true period of rotation. This is called the sidereal day. It is measured by the return to the meridian of a star; for the stars are so immensely far away that, unlike the sun, their position in the sky remains practically unchanged by the earth's revolution. (There is a slight change, the annual parallax, but too insignificant to measurably affect the length of the day). However, although the sidereal day has the advantage of indicating the true period of the earth's rotation, it is unavailable for use in the ordinary affairs of life because it does not accord with the apparent movements of the sun, upon which the phenomena of day and night, sunrise, sunset, etc., depend. Sidereal noon, which occurs when the Vernal Equinox, or First Point of Aries, among the stars, crosses the meridian, comes at some seasons in the daytime and at others in the night. This would never do for ordinary people, but it doesn't trouble the astronomer, who has in the observatory his sidereal clock, which tells him the hour by the stars,—and many a cool, delightful, **stellar noon** does he enjoy while the rest of mankind are asleep.

The length of the sidereal day, measured in solar mean time, is about 23 hours, 56 minutes, 4 seconds, the length of the mean solar day being just 24 hours. Accordingly the solar day is about four minutes longer than the sidereal day, and in a year mean solar time gains one whole day upon sidereal time, so that there are $366\frac{1}{4}$ sidereal days in a year against $365\frac{1}{4}$ solar days. A little reflection will show that this explains the apparent eastward revolution that the sun makes around the heavens, with respect to the stars once every year. It also explains why a given star rises, on the average, four minutes earlier each successive night. About March 22 every year sidereal noon and solar noon coincide. The sidereal time at solar mean noon for any day of the year is given in the Ephemeris.

There are not only two but three kinds of year—the Sidereal Year, the Tropical Year, and the Anomalistic Year. The first is measured by the time taken by the sun in making one apparent revolution around the heavens with respect to a fixed star. Its length is 365 days, 6 hours, 9 minutes, 9 seconds of mean solar time. The second kind of year, the Tropical Year, is measured by the time taken by the sun to make one apparent revolution with respect to the Vernal Equinox. This is the year on which chronology and the calendar are based. Its length in mean solar time is 365 days, 5 hours, 48 minutes, $45\frac{1}{2}$ seconds. The third kind of year, the Anomalistic, is measured by the time that the sun takes to pass from Perihelion to Perihelion, and its length is 365 days, 6 hours, 13 minutes, 48 seconds. It has practically no interest except to astronomers.

THE STANDARD TIME ZONES

The Standard Time System, on which railroad schedules are based, together with practically the whole chronology of business and industry as well as of social life, presents one of the most striking evidences of the rapidity of movement that characterizes all human affairs in our day. Until well toward the close of the Nineteenth Century transportation on land had not become rapid enough to introduce any serious complication by its relation to the speed of the earth's axial rotation, or the index of that rotation furnished by the sun's daily westward progress through the sky.

But in the early eighties it became evident that the growing speed of railroad travel, and the increasing complexity of time schedules covering the whole width of a continent, imperatively demanded a general readjustment of the time shown by clocks and watches to that indicated by the movements of the mean sun, which is the fundamental time-keeper for the entire earth. The result was the adoption, in 1883, by general agreement among the American railroads, of a system of standard time, based on the meridians of longitude in such a way that all places included within certain bounding meridians should have the same time without regard to local differences arising from their being situated, some a few degrees farther west, and others a few degrees farther east. In the same year, an international conference held at Washington discussed and approved the plan, together with suggestions looking to the world-wide adoption of a universal time standard based on the meridian of Greenwich as the common origin.

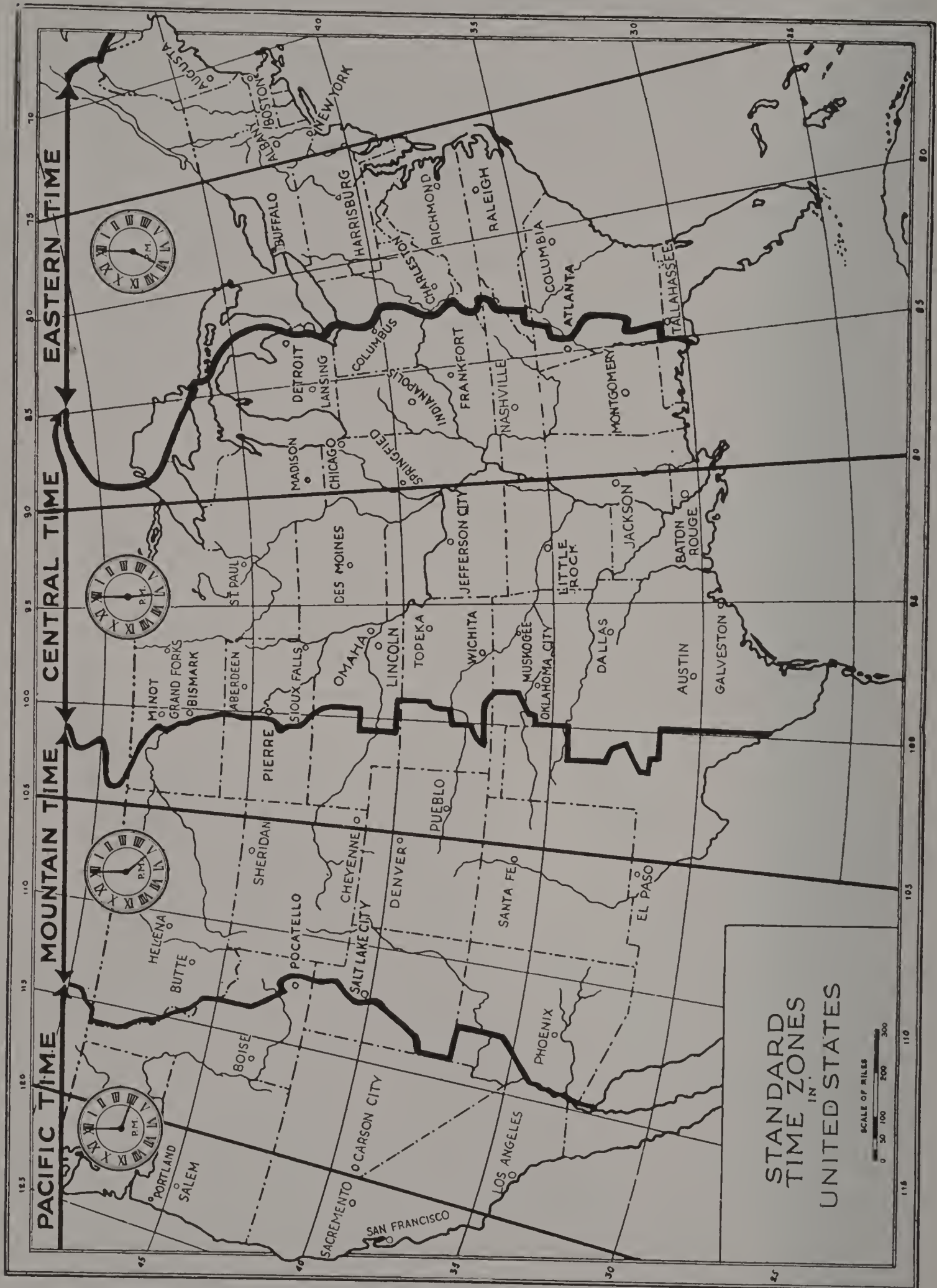
Put into a few words, the principle of the system is as follows. Starting from the meridian of Greenwich and counting westward around the earth, (which is the way of the sun), every 15 degrees of advance in longitude corresponds to one hour of time, because there are 360 degrees in the circumference of the earth, and the sun, taking 24 hours to go once around, must go 15 degrees, or one 24th of 360 degrees in one hour.

Accordingly, when the sun is on the noon line at Greenwich it must be one hour east, or short, of the noon line at a place 15 degrees west of Greenwich; two hours short at a place 30 degrees west, and so on. In other words, noon (or any other chosen hour) arrives one hour later for every 15 degrees that the place of observation is farther west. So, as the observer travels westward, his watch, unless continually reset, steadily gains time on, or gets more and more ahead of, the local time-pieces keeping the time of the places through which he passes.

To prove this it is not necessary to start from Greenwich, for the principle holds all around the world.

For instance, suppose you start from Chicago any day at noon, and travel directly west. When you have gone 15 degrees, which carries you into western Nebraska, your watch marks noon when the sun is still an hour short of the noon line, and when the local clocks mark 11 A. M. And if you go another 15 degrees, into southeastern Oregon, your watch

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will mark noon two hours ahead of the local timepieces (if they are set to true local time).

If you traveled eastward instead of westward the effect would be reversed.

Starting at noon from Chicago, and carrying local Chicago time, when you arrived at the Connecticut river, you would have gone 15 degrees eastward, or 15 degrees to meet the sun, and your watch would be slow by local time, because it would mark noon an hour after the sun had crossed the noon line.

Now, in the days when men in general stayed pretty close to their homes, and when transportation and travel were mostly confined to short distances and brief periods, no great disadvantage was felt from discrepancies of time arising from differences of longitude, because in those days such discrepancies were not large. But, as we have already remarked, the case assumed a very different aspect as soon as fast railroad trains began to transport people as far as from New York to Chicago between suppertime and breakfast. That meant an hour difference of time produced during a night's sleep.

In fact, it is not possible to get rid of these time differences—the best that we can do is to regulate and systematize them. It would not be possible to keep a watch, or a clock, or a time schedule, in absolute and instantaneous accord with the changing local time as an observer moves east or west, for the sun does not suddenly leap from one 15-degree longitude line to the next at the beginning or the end of every hour, but it continually advances in step with the rotation of the earth, so that even in the short time of four minutes it moves one degree westward.

However, a degree of longitude on the earth's surface, within the regions where the population is greatest, is between 50 and 60 miles long, and a difference of time of only four minutes, or even of several times four minutes, is not a very serious matter, provided that its effects are guarded against in cases where they do become of importance. Such provision is made by the Standard Time system.

In the Standard Time system, as applied in this country, four meridians of longitude, separated by interspaces of 15 degrees, are taken as the central lines, or axes, of four successive time zones, each one hour, or 15 degrees, broad, while together they cover the whole width of the United States from the Atlantic to the Pacific. Each zone theoretically extends $7\frac{1}{2}$ degrees on each side of its central meridian, or axis. All places included in one of these four zones have the same standard time, which is the time of the central meridian of that particular zone. This, of course, does not affect the local time of such places, that time continuing to be governed by the relative situation in longitude. But, for nearly all purposes of everyday life, the local time is disregarded and clocks and watches in every part of a given zone are set to the time of its standard meridian. Places just on that meridian have identity of local and standard time.

But since the zones extend $7\frac{1}{2}$ degrees on each side of their central lines, the local time of a place situated near one of the borders of

any zone differs half-an-hour from the time of the central meridian. This is, theoretically, the greatest amount by which the local time of any place can differ from the standard time of its zone, but two places situated on the opposite borders of a zone differ a whole hour in their local time.

In passing from one zone to the next, the time changes by just one hour, the clock being set back if the passage is from east to west, and ahead if from west to east. This may be better understood if we refer to the accompanying chart. There it will be seen that the first of the four zones covers the Atlantic coast states, beginning at the north-eastern corner of Maine. Its central, or standard meridian, is the 75th meridian west of Greenwich, which crosses the country a little west of New York, and very close to Philadelphia. The time of that meridian is five hours slow on Greenwich, i. e. when it is noon at Greenwich it is 7 A. M. of the same day on the 75th meridian. This is called Eastern Standard time.

Now, the whole of the New England states and Middle states, and a large part of the Southern states, are included in the 75th meridian zone, a space hundreds of miles wide, and within which the local times may differ by a whole hour; yet under the Standard Time system, their watches and clocks all keep together, so that there is no need to change the setting of your watch until you pass across the western border of the zone, which crosses the Great Lakes, and runs near Detroit, Columbus, and Atlanta. When you cross that border going west, you set your watch just one hour back.

Then you have the time of Chicago and the Middle West, called Central Standard time, whose meridian is the 90th, or six hours slow on Greenwich. And this you keep unchanged until you cross into the zone of Mountain Standard time, whose central meridian is the 105th, while its time is seven hours slow on Greenwich. The fourth of the zones, on entering which from the east you set your watch back another hour, is that of Pacific Standard time, centered on the 120th meridian, eight hours slow on Greenwich. But, except to show the common origin of the system from a world view-point, there is no need to refer back to Greenwich, the time of the Eastern, or 75th meridian, zone serving for a starting point.

We have seen that if a place is on the eastern border of its zone, $7\frac{1}{2}$ degrees from the central line, its local time is half an hour fast by the central standard, while if it is on the western border its local time is half an hour slow. But now consider the situation of things with regard to two places just facing one another, and virtually in contact, one being on the western and the other on the eastern border of its own zone. Their local time would be practically the same, but by Standard time they would be one hour apart, just as if they were actually separated by 15 degrees of longitude, or a distance of about 750 miles.

Such cases as this may serve to illustrate the origin of the zig-zag shape of the border lines between the zones as shown in the chart. While the central line of each zone is strictly coincident with the corres-

ponding meridian of longitude, whose time fixes the standard for the whole zone, the border lines do not, as they theoretically should do, follow meridians but are very crooked, swerving sometimes east and then again west, as sinuous in their course as rivers. A large part of the western border of the Central zone is thrown beyond the 100th meridian, which puts it more than 10 degrees, instead of $7\frac{1}{2}$ degrees from its central meridian, the 90th.

These variations are due to efforts of the Interstate Commerce Commission to adjust conflicting interests and wishes of the inhabitants of the regions traversed by the boundaries. According to information furnished by the Superintendent of the U. S. Naval Observatory the chief reasons determining the courses of the boundary lines, which have many times been modified, while at the start no attempt seems to have been made to keep the zones exactly 15 degrees wide, are as follows:

(a) Grouping of railroads and other commercial routes into divisions or sections having the same time; for example, variation of the boundary line to include a terminal or important center in the same division, or area, as the larger part of the roadway.

(b) Unifying the time system of certain areas having natural boundaries, such as rivers, lakes, mountains, etc.

(c) Generally avoiding divisions of counties, townships, and cities.

(d) Passing the boundary lines generally through the less densely populated areas, and avoiding division of more densely populated communities.

(e) Satisfying the demands of the people of certain areas and sections near the boundaries of the zones by giving them local benefits or advantages.

It may be added that, although it is not shown, except a little corner, on the United States chart, there is another zone, used in Canada, and known as the Intercolonial, whose central meridian is the 60th, four hours from Greenwich, while it includes Newfoundland, Nova Scotia, New Brunswick, and a part of Quebec within its area.

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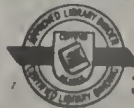


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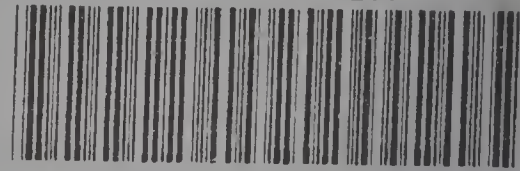
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